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THE ACCURACY OF DRIVERS' PERCEPTIONS OF THE EFFECTS OF HEADLIGHT GLARE ON THEIR ABILITY TO RECOGNIZE PEDESTRIANS AT NIGHT

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THE ACCURACY OF DRIVERS' PERCEPTIONS OF THE EFFECTS OF
HEADLIGHT GLARE ON THEIR ABILITY TO RECOGNIZE
PEDESTRIANS AT NIGHT

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Applied Psychology

by
Stephanie Anne Whetsel
December 2011

Accepted by:
Dr. Richard Tyrrell, Committee Chair
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Dr. Patrick Rosopa

ABSTRACT

Recently, researchers have begun to assess the extent to which drivers believe their ability to see is degraded by headlight glare. Research has suggested that drivers may overestimate the extent to which glare from headlamps degrades their ability to see letters. This project extended this research by quantifying the accuracy with which drivers judge that glare interferes with their ability to see pedestrians at night. On average, participants overestimated the distance at which drivers would see a pedestrian by a factor of more than three. Headlight glare disrupted participants' ability to recognize the pedestrian wearing both non-retroreflective and reflective clothing configurations. Interestingly, participants judged that headlight glare would not affect recognition distances for a pedestrian wearing a retroreflective vest, while judgments of recognition distances for the lower contrast pedestrian decreased appropriately. Future research should explore situations in which drivers' misjudgments of their own perceptual capabilities may cause predictable problems.

ACKNOWLEDGMENTS

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INTRODUCTION

Substantial evidence suggests that pedestrians are often dangerously inconspicuous to drivers at night. The number of crashes that result in pedestrian deaths is three to four times higher at night than in daylight hours (Plainis & Murray, 2002). Plainis and Murray also found that as a target's conspicuity decreased, people's reaction times to those objects significantly increased. Hazlett and Allen (1968) reported that almost 90% of drivers who were involved in a nighttime collision in which their vehicle struck a pedestrian stated that they had trouble seeing the pedestrian prior to the incident. Additionally, just over 23% of those drivers did not recognize the object they had struck as a pedestrian until after the crash had already occurred. Research (e.g., Wood, Tyrrell, & Carberry, 2005; Wood, Tyrrell, Chaparro, Marszalek, Carberry, & Chu, 2010) has shown that the presence of headlamp glare further decreases drivers' ability to recognize pedestrians at night.

Addressing the possibility that glare from the headlamps of opposing vehicles can increase the risk to pedestrians, the findings of a recent study (Balk & Tyrrell, 2010) suggest that road users may overestimate the extent to which glare degrades their own visual acuity. The purpose of the present study is to further explore these findings by asking participants to estimate their ability to recognize a pedestrian when headlamp glare is present. Estimates will then be compared to participants' actual ability to recognize pedestrians at night in the presence of glare. It is expected that participants will underestimate the distances at which they would be able to recognize pedestrians when glare is present. A review of existing literature will first discuss the benefits and usage of

high beam headlamps, followed by research regarding headlamp glare and its effects on drivers at night. The present study will then be discussed more fully.

Drivers can take steps to improve their own ability to detect pedestrians at night by using high beam headlights. Sullivan and Flannagan (2001, cited by Sivak, Flannagan, Schoettle, & Adachi, 2003) reported that over 2000 pedestrians die per year in the United States due to drivers' decreased ability to see when driving at night. Olson and Sivak (1983) measured the frequency with which participants' visibility distances were less than the stopping distance that had been previously calculated. They found that for younger drivers driving a vehicle that used standard low beams who were exposed to a pedestrian wearing a dark shirt, visibility distances were less than the stopping distance on 45% of the trials. For older adults, 83% of trials in which pedestrians wore a dark shirt resulted in dangerously short visibility distances. Thus when drivers rely on their low beam headlamps at night they are often unable to see pedestrians until it would be too late to stop the vehicle, avoiding a collision.

Wood, Tyrrell, and Carberry (2005) demonstrated the value of using high beam headlights at night. Participants drove a closed road course using either low or high beam headlights and encountered a pedestrian who walked in place and wore all black, all white, all black with a retroreflective vest, or all black with biomotion reflective markings. Wood et al. found that participants detected only slightly more than 60% of pedestrians when driving with low beams. In contrast, almost 75% of pedestrians were detected when drivers utilized high beams. These findings highlight the benefit of high beam usage in pedestrian detection at night. By providing more illumination on the

distant roadway ahead, high beam headlights extend recognition rates and distances for drivers by enhancing the contrast of pedestrians.

Despite the benefits of high beam usage in improving nighttime visibility, drivers under-use their high beam headlights. Hare and Hemion (1968; as cited by Schwab & Hemion, 1972) recorded headlight usage on a variety of roadways in 15 different states. They found that 75% of drivers used their low beam headlights when high beams would have been more appropriate (i.e., no opposing or leading vehicles on the roadway). More recent studies of beam usage have yielded similar findings. Sullivan, Adachi, Mefford, and Flannagan (2004), for example, observed headlight usage on rural roads with no roadside lighting, making judgments for only those vehicles that were considered “clear” (i.e., no opposing, leading, or following vehicles present). Based on the judgments made in this study, Sullivan et al. found that high beams were only used 50% of the time, despite the fact that only “clear” vehicles were judged. This indicates a serious underuse of an intervention that is required to be present in all vehicles.

Both Mefford, Flannagan, and Bogard (2006) and Buonarosa, Sayer, and Flannagan (2008) asked participants to drive instrumented vehicles for 7-27 days during which data were collected on (among other variables) the usage of low and high beam headlights. Mefford et al. (2006) found that 21% of the total miles driven were driven at night. During the periods of time in which the vehicle was driven at night, high beams were only used 3% of the time. Even drivers who were not following other vehicles and/or did not encounter any oncoming vehicles used their high beams just 25% of the distance driven at night.

Similarly, Buonarosia et al. (2008) found that approximately 23% of the total distance driven took place at night. High beams were used around 10 minutes for every 100 km driven at night. In comparison, low beams were used an average of almost 100 minutes for every 100 km driven. Like Mefford et al., these authors concluded that drivers underuse their high beams at night, even under ideal conditions (i.e., no opposing or leading vehicles present).

It is possible that typical drivers do not recognize the increased visibility benefits of high beam usage, and are unaware of the dangers of the decreased levels of visibility afforded to them by low beams. Tyrrell, Patton, and Brooks (2004) conducted an experiment in which participants were either assigned to a condition in which they were educated about pedestrian visibility or to a control condition. Participants were asked to estimate the distance at which they thought they would just be visible to a driver while wearing one of three clothing conditions (all black, all white, and a biomotion retroreflective configuration). A test vehicle used either low or high beam headlamps as the participants made their estimates of the distance at which the driver would just be able to see them. Tyrrell et al. found that participants in the control condition (who had not been exposed to any sort of educational intervention) estimated their visibility distance to be greater when the driver was using high beams in comparison to the use of low beams. However, the mean distance estimated in the high beam condition was only 6% longer than that found in the low beam condition. This finding indicates that participants did not fully recognize the benefits of high beam headlights. Wood et al. found an increase of just over 30 meters in drivers' detection distances when high beams

(mean detection distance of approximately 94 m.) were used, as opposed to low beams (mean distance of approximately 60 m).

While research (e.g., Tyrrell et al., 2004) indicates that many drivers under-appreciate the benefits of high beams, it may be the case the drivers are acutely aware of the effect of their use of high beams may have on oncoming drivers. If this is the case, it is important to determine exactly what effect, if any, glare has on drivers' ability to see at night—do the potential decrements warrant the underuse of high beams? Over the years, the National Highway Traffic Safety Administration (NHTSA) has received an increasing number of complaints from drivers regarding glare. Many drivers refer to glare from oncoming vehicles as “blinding.” Singh and Perel (2003), on behalf of the NHTSA, conducted a survey in order to better understand drivers' perception of glare. Participants were asked “In the last 12 months, while driving at night, has the glare from the headlights of an oncoming vehicle been ‘*not noticeable*,’ ‘*barely noticeable*,’ ‘*noticeable but acceptable*,’ ‘*disturbing*,’ or did it cause a ‘*crash or near miss*’?” A small percentage of the respondents reported that glare was “not noticeable” or “barely noticeable.” Almost 60% of respondents perceived glare to be “noticeable but acceptable,” while around 30% stated that glare had been “disturbing” to them. Finally, 1% of respondents reported that glare had been responsible for a “crash or near miss.” The fact that a rather large percentage of drivers perceive glare as disturbing may be a large causal factor in the underuse of high beams. The fact that drivers feel discomfort when faced with glare may lead them to believe that they are also disabled. Drivers may then avoid the use of high beams in order to prevent the occurrence of glare to other drivers.

In assuming that their high beams are disabling to oncoming vehicles, drivers may be failing to distinguish between disability glare and discomfort glare. In a NHTSA (2007) report, disability glare is defined as being present when light from an oncoming vehicle scatters in the eye, creating a “veil” that decreases drivers’ visibility distances and reduces the contrast of objects in the environment. Discomfort glare is the subjective feeling of annoyance and/or pain associated with exposure to glare. Drivers are acutely cognizant of their subjective experiences with glare from oncoming vehicles, but may not understand or appreciate the extent to which their ability to see at night is affected by glare.

Surprisingly little research has determined the effects of glare from oncoming vehicles on drivers’ ability to detect pedestrians. In the study by Wood, Tyrrell, and Carberry (2005), the researchers also studied the effects of glare on pedestrian conspicuity. Prior to encountering each test pedestrian, a glare source was turned on for some of the trials. Recall that participants were asked to indicate when they could first see the pedestrian; recognition rates were measured. Wood et al. found that only 61% of pedestrians were recognized when glare was present, versus 76% when it was not.

Wood, Tyrrell, Chaparro, Marszalek, Carberry, and Chu (2010) conducted an experiment that examined the separate and combined effects of glare and simulated visual impairments on drivers’ ability to recognize pedestrians. Participants drove a closed-road course and experienced three different visual conditions (normal vision, blurred vision, and simulated cataracts). The participants’ visual acuity was always 20/40 or better even when the simulated visual impairments were present. One group of participants

completed the experiment with no headlamp glare, while another group encountered a glare source prior to the test pedestrian. Wood et al. reported that response distances were significantly decreased in the presence of glare, as were response rates. The effect of glare was particularly debilitating when participants drove with lenses simulating cataracts. The findings of both Wood et al. (2005) and Wood et al. (2010) confirm that the presence of headlamp glare results in significant decrements in drivers' ability to recognize pedestrians at night.

Theeuwes, Alferdinck, and Perel (2002) examined not only how glare affects drivers' ability to detect pedestrians, but also the subjective feelings of discomfort associated with glare. Participants drove a vehicle that had lights mounted on the hood to simulate headlights from an oncoming vehicle. The lights were projected towards the driver in one of three intensities, one of which was just barely uncomfortable, one that was meant to be similar to typical European headlights, and one that was meant to be similar to headlights typically used in the U.S. Participants drove a closed course that consisted of nine different sections meant to represent different types of roadways. One of their tasks was to indicate when they saw plywood boards that were meant to simulate a roadside pedestrian. The simulated pedestrians could be on the left or right side of the road anywhere along the road. Theeuwes et al. (2002) found that the presence of a glare source significantly affected the distances at which participants detected the simulated pedestrians. When the glare source was at its highest intensity (similar to luminance level of U.S. low beams), targets were detected at a mean distance of 27.5 m, in comparison to 35.4 m in the no glare condition. Glare also affected the frequency of missed targets, with

more targets being missed as glare intensity increased. The authors also found that subjective discomfort experience by participants when faced with glare (measured using the deBoer scale) was not predictive of participants' driving performance. Theeuwes et al. concluded that "the [deBoer] scale, the most commonly used rating scale for discomfort glare, is practically useless as a predictor of driving performance" (p. 106).

Flannagan, Sivak, Traube, and Kojima (2000) also lent support to the hypothesis that the visual discomfort resulting from exposure to glare is independent from the effects of glare on vision. In their study, two racks of lights were utilized; one was meant to simulate the headlights of the car participants sat in, while the other simulated headlights from an oncoming vehicle. The researchers varied the intensity of both sets of lights so that the intensities of both sets were always matched. Participants sat in the test vehicle and were asked to hit the horn button in the vehicle when they could just see a pedestrian as he walked toward them, and then indicate when they could no longer see him as he walked away from the test vehicle. The pedestrian would either be walking in the center of the road or along the right shoulder of the roadway. The pedestrian made note of his position on the road when he heard the horn.

The results showed that visibility distances increased by almost 20% as the intensities of the two light sources increased simultaneously. That is, visibility distances increased as both test vehicle and glare source intensities increased. The researchers also found that as the intensity of the glare source increased, ratings of discomfort glare also increased. The fact that higher levels of oncoming glare produced both greater levels of

discomfort and increases in pedestrian visibility reveals that it is possible to dissociate disability glare from discomfort glare.

Thus, research has documented both drivers' perceptions of glare (e.g., Singh & Perel, 2003) and actual decrements in performance when glare is present (e.g., Theeuwes et al., 2002; Wood, Tyrrell, & Carberry, 2005; Wood et al., 2010). However, there is little research concerning the extent to which drivers' perceptions of the effects of glare on their ability to see are accurate. Two recent experiments by Balk and Tyrrell (2010) are the first to address this issue. In the first experiment, participants sitting in a laboratory used two different techniques to estimate their own visual acuity in the presence of three different intensities of glare. There was a strong correlation between ratings of discomfort glare and estimated acuity; that is, in conditions with elevated levels of discomfort, participants' estimated their own acuity to be worse. However, actual acuity was unaffected by glare, and ratings of discomfort were not correlated with actual measurements of acuity.

Their second experiment examined the same issue in a context that was closer to that of nighttime driving. Participants, sitting in a vehicle on a closed road at night, first estimated the distance at which they would just be able to determine the orientation of a high contrast Landolt C stimulus under four lighting conditions (varying the beam setting of both the test vehicle and a "glare vehicle" that faced them). After participants estimated the distance at which they would be able to determine the orientation of the stimulus, their actual visibility distances were measured by slowly driving the test vehicle towards and away from the stimulus until the participant indicated he or she was just able

to determine the orientation of the Landolt C stimulus. Once again, actual visibility distances were not affected by the glare manipulations but participants judged that the glare produced by the high beam headlights of the opposing vehicle would result in significantly shorter visibility distances than would the low beam glare. Based on the results of experiments one and two, Balk and Tyrrell concluded that drivers can overestimate the effects of glare on visual acuity and that the discomfort felt by drivers facing a glare source can be associated with the driver overestimating the extent to which their ability to see is degraded by the glare.

Although the second experiment conducted by Balk and Tyrrell (2010) was conducted on a closed-road (and not in a laboratory), it was only the first such experiment and the effect needs to be replicated with both similar and novel methods. One limitation of the study was that it relied on a high-contrast stimulus that may have improved participants' acuity beyond that which could have been degraded by the relatively mild levels of glare. Additionally, the task of detecting the orientation of a high contrast letter may not necessarily be predictive of detecting the kinds of objects that can be encountered in nighttime driving. Pedestrians, for example, are often low-contrast, unexpected, and not always detected foveally. For these reasons, the results of Balk and Tyrrell (2010) need to be explored in the context of pedestrian recognition.

The present studies sought to determine the extent to which drivers under- or overestimate the visually disabling effects of glare when the target is a pedestrian. In order to examine the full extent to which observers accurately estimated the effects of glare, in Experiment 1 participants imagined that a pedestrian was present on the shoulder

of the road adjacent to a vehicle that may or may not have headlamps activated. By asking participants to imagine the presence of a pedestrian, participants were forced to estimate the effect of headlight glare on their ability to recognize the presence of a pedestrian at night. Participants in Experiment 2 indicated the point at which they first recognized the pedestrian was present in the presence of headlight glare. Both experiments took place at night. One of three glare conditions were presented by the opposing vehicle used in both experiments: lights off (just parking lights on), low beam headlights combined with fog lights, and the low beam-fog light combination with neutral density filters (ND 1.2) that limited the amount of light that was emitted from each light source. In a study that quantified pedestrians' estimates of their own visibility, Whetsel, Rosenberg, Balk, and Tyrrell (2011) utilized neutral density filtered headlamp manipulations and found that participants generally did not notice the use of filters. In that study the participants' estimates of their own visibility did not vary with headlamp illumination even when the headlamp illumination was reduced by 97%, providing further evidence that participants were not aware of the decreased illumination caused by filters. In the present studies, it was expected that participants in Experiment 1 might detect the decreased illumination resulting from filters, as estimates were measured within-subjects. None of the participants in either experiment was told that one of the headlamp conditions would result in decreased illumination through the use of filters. However, participants in both experiments were surveyed at the conclusion of data collection to ensure the headlamp manipulation remained undetected. The test vehicle that carried participants used low beam headlights at all times. The test pedestrian wore

one of two clothing conditions: street clothing (khaki colored pants and a blue turtleneck) or the street clothing with the addition of a retroreflective vest in order to enhance conspicuity.

It was hypothesized that there would be main effects of both glare intensity and clothing condition for Experiment 1. Recall that Experiment 1 asked participants to estimate the distance at which they would first recognize a pedestrian. Based on previous research (e.g., Balk & Tyrrell, 2010), it was expected that estimates of recognition distance would significantly decline as glare intensity increased. When the estimated recognition distances are averaged across the glare intensities, it was expected that the Vest condition would yield longer estimated recognition distances than the Street Clothing condition.

Experiment 2 examined the effect of both glare intensity and clothing condition on participants' ability to see a pedestrian walking in place adjacent to the glare vehicle. It was predicted that there would be a slight effect of glare intensity on recognition distances. A main effect of clothing condition was expected, such that the Vest condition would result in longer recognition distances than those associated with the Street clothing condition.

At the conclusion of data collection for both experiments, I examined the difference in the effect of glare on response distances. I predicted that glare intensity would not have as large of an effect on recognition distances (Experiment 2) in comparison to estimated recognition distances (Experiment 1).

EXPERIMENT 1

Method

Participants

Twenty-three Clemson University undergraduate students (11 females, 10 males) 18-25 years of age ($M = 19.14$, $SD = 1.11$) participated in this study. Data from two participants were eliminated due to technical difficulties; thus, data from 21 participants are reported. Participants received course credit in exchange for their participation in the study. All participants were required to have normal or corrected-to-normal vision, achieved a visual acuity of at least 6/7.5 (20/25), and reported having no known visual pathology (other than corrected refractive error). Additionally, participants' contrast sensitivity was measured using the Pelli-Robson letter sensitivity chart; all participants achieved a minimum score of 1.65. Participants averaged 4.13 years of driving experience ($SD = 1.36$). On average, participants reported that 36.5% ($SD = 14.5\%$) of their driving took place at night.

Design

The present study included two independent variables: glare intensity and clothing. Both variables were manipulated within-subjects. By manipulating the headlights on the glare vehicle, three levels (Parking, Mild, and Stronger) of glare intensity were used (see Figure 1): none (Parking lights), a neutral density filtered condition (filtering low beams and fog lights; Mild), and low beams combined with fog lights (Stronger). The filters (GAM Products, Los Angeles, CA) reduced the amount of illumination transmitted from the glare vehicle's headlights to approximately six percent

(1.2 log units). Illumination measurements from each glare intensity were taken to determine the exact illumination of each condition. Measurements were taken at the eye height of a 5'6" individual (see Figure 2). Two clothing conditions were used: Street clothing (khaki colored pants and a dark blue shirt) and a Vest condition (retroreflective vest worn over Street clothing). Participants were exposed to all combinations of glare intensity and clothing conditions. The dependent variable measured was the distance at which participants estimated that they would recognize that a pedestrian was present.

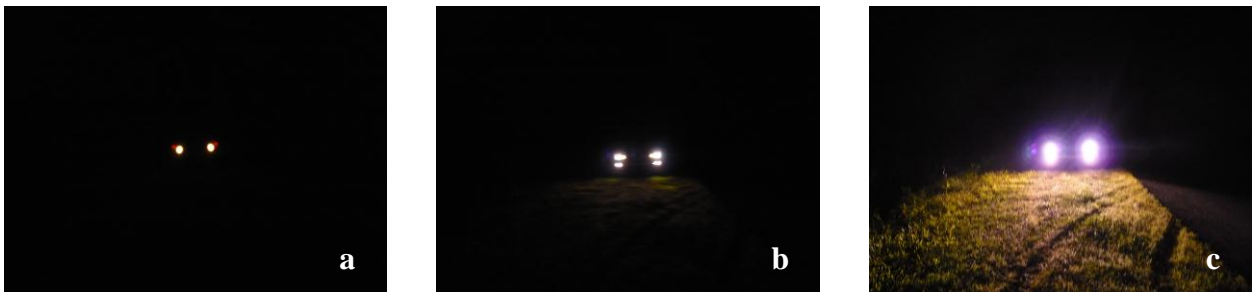


Figure 1. Photographs (taken 15.24 m (50 ft) from the glare vehicle) of the three levels of glare intensities used in both experiments; (a) Parking, (b) Mild, (c) Stronger.

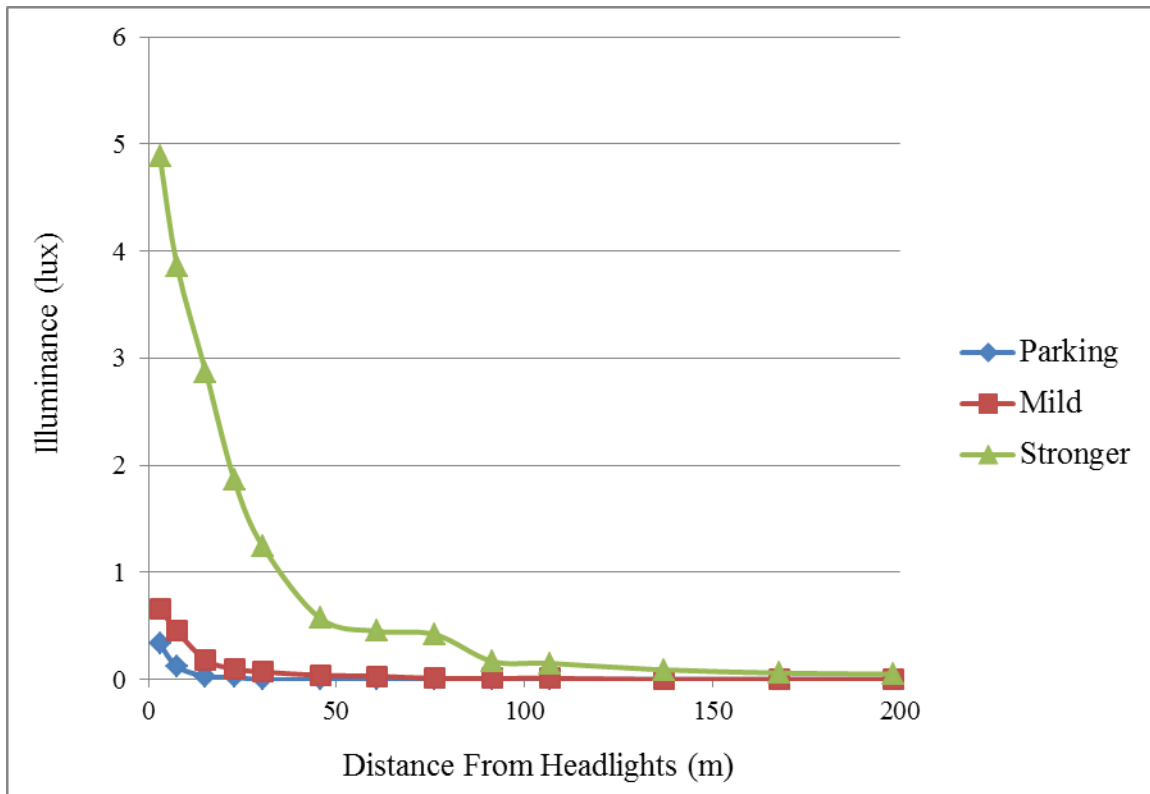


Figure 2. Illumination from the headlights of the glare vehicle as a function of distance for each glare intensity.

Procedure

The first portion of each experimental session took place in the laboratory. After informed consent was obtained, participants' binocular visual acuity was measured using the Bailey-Lovie chart. Contrast sensitivity was assessed using the Pelli-Robson letter sensitivity chart. Following completion of visual testing, the experimental procedures were explained to each participant. They were then walked outside to the test vehicle (2005 Saturn Vue) to be transported to the test site. No data were collected if any inclement weather (e.g. rain, fog) was present or if the roadways were not completely

dry. Prior to each night's data collection, the windshield and headlights of the experimenter's vehicle were cleaned.

The speed of the experimental vehicle did not exceed posted speed limits. The speed of the vehicle was 35 mph (i.e., the road's speed limit) during its approach to the glare vehicle (and test pedestrian in Experiment 2). The experimenter's vehicle used low beam headlights for all trials. The glare vehicle was a 2008 Infiniti EX35 with xenon low beam headlamps.

The test site was an open two-lane roadway located on the Clemson University campus (Old Stadium Road); see Figure 3. Data collection began at least one hour after sunset. The road is a semi-rural two-lane (one lane in each direction) roadway with relatively low traffic density and has one street light. The glare vehicle/pedestrian location was selected such that sight distance (200 m) was maximized.

For both experiments, participants were given a response keypad connected to a laptop computer. When the participant pressed the button on the keypad, the distance that separated the test vehicle and the glare vehicle/pedestrian was calculated based on the speed of the test vehicle. A linear regression model was calculated to determine the accuracy of the distance calculator (see Figure 4). The results of the regression that used the measured distance to predict the true distance (measured by walking with a measuring wheel) indicated an R^2 value of .999, $F(1,9) = 7410.12$, $p < .0001$. The resulting regression equation ($Y = 1.003x - 9.19$) was used in both Experiments 1 and 2 to correct the distances calculated to ensure accuracy.



Figure 3. The roadway on which the glare vehicle was located during data collection. The circle represents the approximate location of the glare source (and pedestrian in Experiment 2). The arrow represents the direction in which the glare vehicle faced during data collection. (Map was taken from Google Maps, <http://maps.google.com>.)

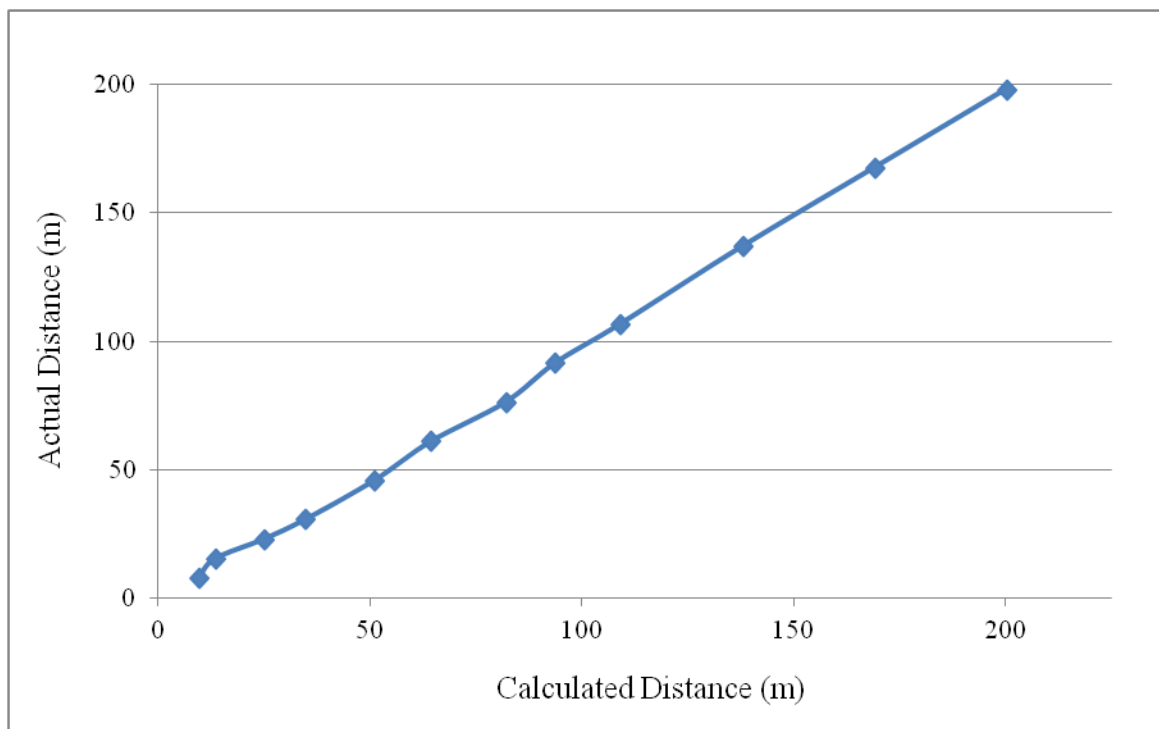


Figure 4. The linear regression model to determine the accuracy of the distance calculator

Participants were shown two photographs prior to departing for the test site. The photographs (see Figures 5a and b) showed a pedestrian wearing each of the two clothing configurations (Street and Vest). The photographs showed the clothing configurations in daytime lighting, taken at the test site with the pedestrian standing 7.62 meters (25 ft.) from the photographer. In addition, before they left the laboratory to start their drive, participants were encouraged to examine the clothing items that they were to imagine being worn by the test pedestrian. Participants were instructed to examine the clothing and photographs closely, as they needed to keep the items in mind for the task they would complete. The photographs were again shown to them in the test vehicle prior to the start of each trial as well. After participants viewed the necessary items, an in-vehicle experimenter gave the following instructions: “Imagine that a pedestrian is walking in place next to the stationary vehicle that you saw in the photograph. Please press your button at the moment when you are confident that you would just be able to recognize that a pedestrian were present and standing next to the car that is parked on the shoulder. Remember that there is no pedestrian standing next to the car; you are just imagining that this pedestrian is there and that he is wearing this [indicate photograph depicting relevant clothing condition].”



Figures 5a and b. Photos shown to participants of the two clothing conditions in order to assist them in making their estimates of recognition distance. The Street clothing condition is represented in the photo on the left; Vest condition in the right.

Either one or two participants completed the protocol at a time. During trials in which two were present, one sat in the front seat and one in the rear seat; participants who were tested alone always used the front passenger seat. Before beginning data collection, the experimenter drove past the glare vehicle, making participants aware of its location on the left shoulder of the road. The experimenter in the backseat then reminded the participants to imagine that the pedestrian is present and they should press the button on the controller when they are confident that they believe they would just be able to see the pedestrian. Participants completed six trials, the order of which was randomized for each

pair of participants. At the start of each trial, the experimenter in the backseat informed the participants of the clothing condition they should envision when making their estimates. The experimenter shared a photograph of the pedestrian wearing the relevant clothing configuration. The test vehicle completed a lap of the experimental route (see Figure 6) for each of the six trials. Laps were repeated whenever there were any other vehicles in view during the test vehicle's approach to the glare vehicle. At the conclusion of data collection, participants were asked to complete a brief survey (see Appendix A).

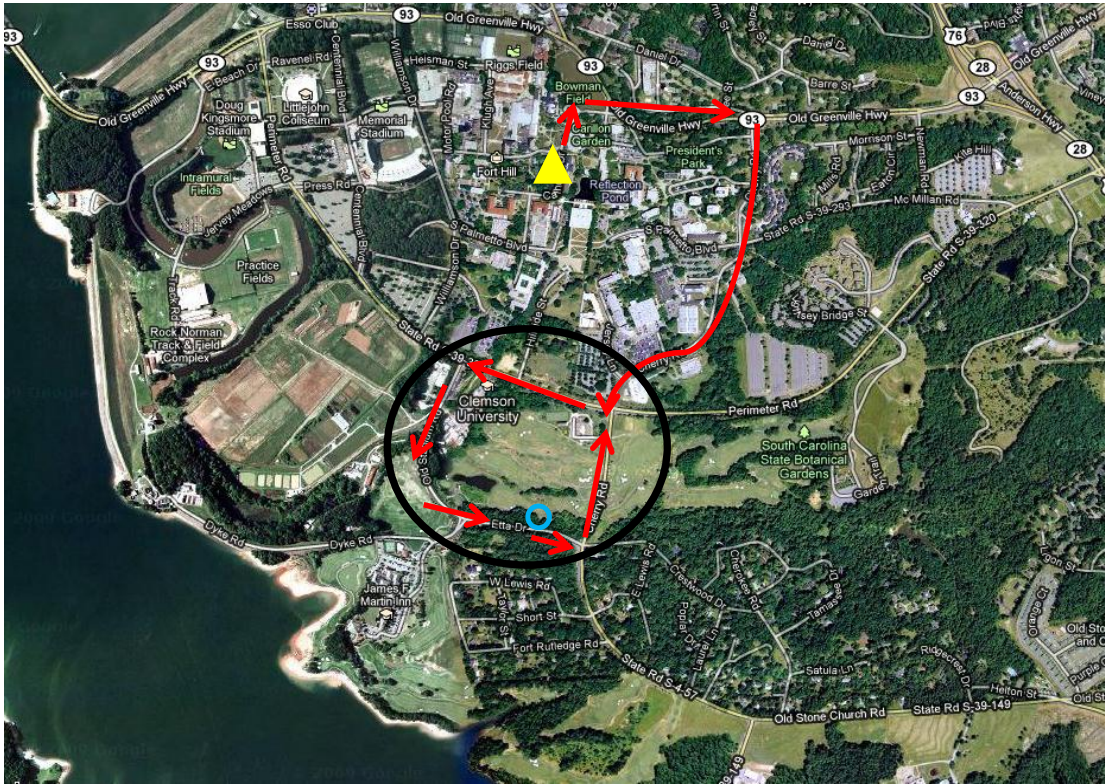


Figure 6. Route driven by experimenter for estimated recognition trials. The triangle represents the start and finish point and the circle represents the position of the glare vehicle. Note that after passing the glare source, the test vehicle looped back around to the site of the glare vehicle for the next trial (area within black circle). (Map was taken from Google Maps, <http://maps.google.com>.)

Results

Prior to analyzing these data, the homogeneity of variance assumption was satisfied. A $3 \times 2 \times 2$ (Glare Intensity: Parking, Mild, and Stronger x Clothing: Street and Vest x Seat: Front or Back) mixed measures ANOVA was conducted using Huynh-Feldt degrees of freedom corrections when appropriate (Huynh & Feldt, 1976).

Seat was treated as a between-subjects factor in order to examine the effect of participants' seat position on estimated recognition distance. Seat did not significantly affect estimated recognition distances, $F(1,19) = .29, p > .05, \eta_p^2 = .01$. Additionally, seat did not interact with either Glare or Clothing, $p > .05$.

There was not a main effect of Glare intensity, $F(1.97, 37.46) = 2.42, p > .05, \eta_p^2 = .11$ (see Figure 7). This finding suggests that when estimated recognition distances were averaged across Clothing conditions, there were no significant differences in estimates among the three Glare conditions: Parking ($M = 120.8$ m, $SD = 48.1$ m), Mild ($M = 114.6$ m, $SD = 53.6$ m), and Stronger ($M = 108.8$ m, $SD = 61.9$ m).

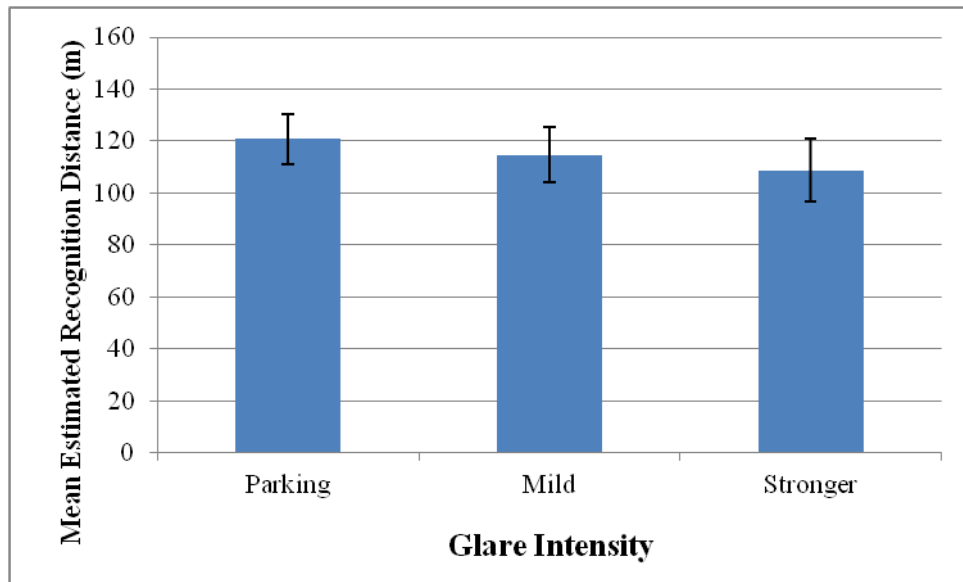


Figure 7. Mean (± 1 standard error of the mean) estimated recognition distances (m) for each of the three Glare intensities. These values were averaged across the two Clothing conditions.

There was a main effect of Clothing, $F(1, 19) = 40.04, p < .001, \eta_p^2 = .68$ (see Figure 8). Participants' estimates when imagining the pedestrian in the Street clothing

condition ($M = 88.1$ m, $SD = 39.7$ m) were significantly shorter than those estimates given when imagining the pedestrian in the Vest condition ($M = 141.4$ m, $SD = 56.5$ m).

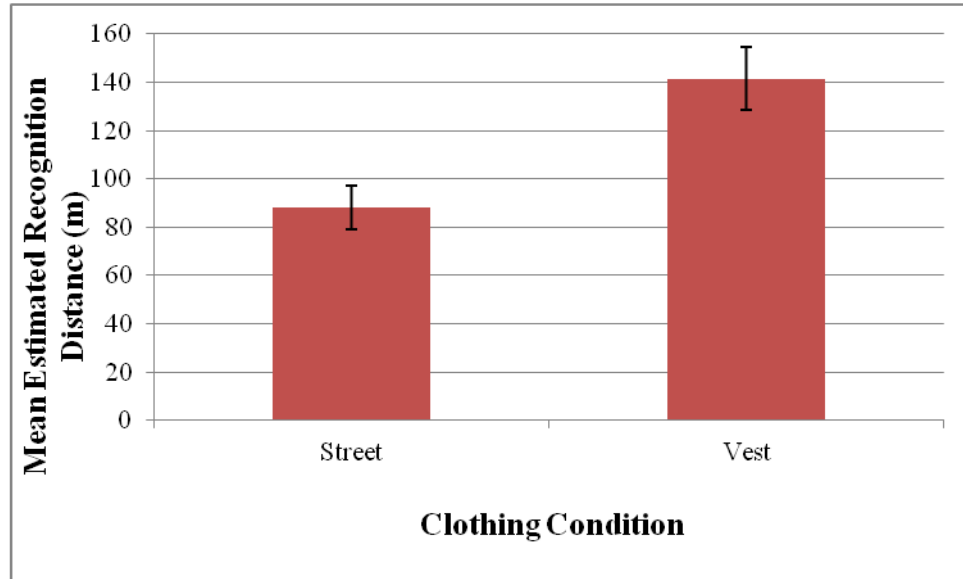


Figure 8. Mean (± 1 standard error of the mean) estimated recognition distances (m) for the two Clothing conditions. These values were averaged across glare intensity conditions.

There was also a significant interaction between Glare intensity and Clothing condition, $F(2, 38) = 4.18$, $p < .05$, $\eta_p^2 = .18$. The Vest condition yielded relatively consistent estimated recognition distances across the three glare conditions. However, there was a decline in estimated recognition distances for the Street clothing condition as Glare intensity increased. This relationship can be seen in Figure 9.

Two one-way ANOVAs were conducted to examine the simple effect of Glare intensity on estimated recognition distances for each of the Clothing conditions. The ANOVA examining the effect of Glare intensity on estimated recognition distances for the Street clothing condition revealed a significant simple effect of Glare intensity,

$F(1.82, 36.35) = 13.48, \eta_p^2 = .40, p < .05$. Bonferroni-corrected follow up tests were conducted to examine mean differences among Parking, Mild, and Stronger estimated recognition distances. The mean estimated recognition distance for Parking ($M = 100.8$ m, $SD = 37.3$ m) was not significantly different from that for Mild glare ($M = 87.2$ m, $SD = 39.2$ m), $p = .09$; mean estimates for both Parking and Mild were significantly longer than distances estimated for Stronger, ($M = 73.8$ m, $SD = 39.8$ m), $p < .05$.

There was not a significant simple effect of Glare intensity on estimated recognition distances for the Vest, $F(2, 40) = .23, \eta_p^2 = .01, p > .05$. Estimated recognition distances did not significantly vary among the three Glare intensities: Parking ($M = 140.2$ m, $SD = 50.4$ m), Mild ($M = 137.7$ m, $SD = 55.0$ m), and Stronger ($M = 134.7$ m, $SD = 65.7$ m).

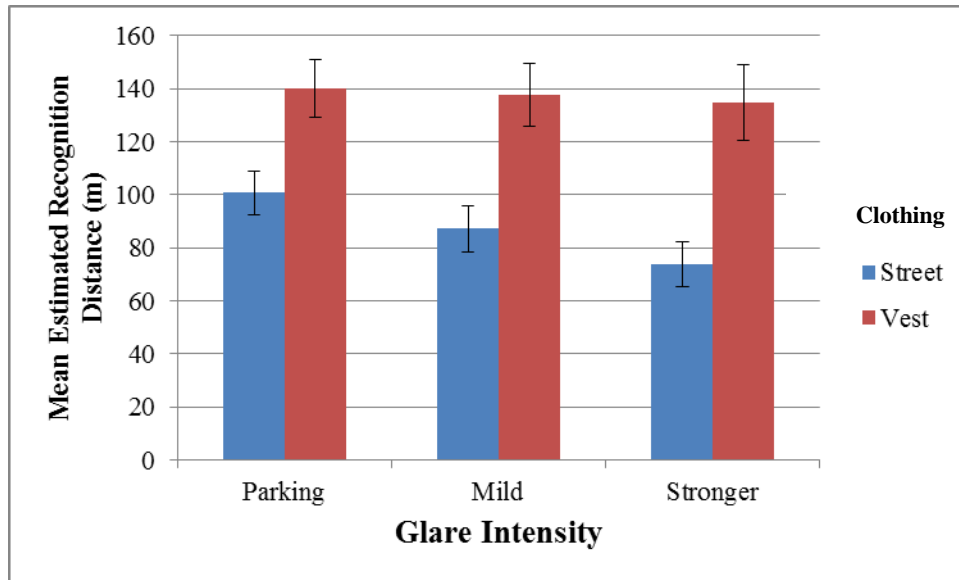


Figure 9. Mean (± 1 standard error of the mean) estimated recognition distances (m) for all the combinations of the three Glare intensities and two Clothing conditions. The interaction between Glare intensity and Clothing condition was significant.

An examination of the survey results of the 21 participants' whose data were available showed that eight (38.1%) of the participants reported noticing something unusual about the glare vehicle. This question served to determine whether participants noticed the use of neutral density filters. Of the eight participants who said they noticed something unusual, six (28.6% of total sample) went on to explain that the headlights were changed for each trial. One participant simply stated the headlights were on and another commented on the safety triangles placed at the rear of the glare vehicle. Safety triangles had been placed at the rear of the glare vehicle and oriented such that only oncoming traffic could see them. A participant who twisted around to look backwards after passing the glare vehicle could see the triangles as well.

Participants were also asked to rate how similar the glare vehicle's headlights were to typical headlights. These ratings were on a one-to-four scale where one was 'exactly the same' and 4 was 'significantly different.' Six (28.6%) participants rated the headlights as exactly the same, nine (42.8%) rated them as being 'slightly different,' and four (19%) rated the headlights 'somewhat different.' Only three (14.3%) participants mentioned that the glare vehicle's headlights appeared dimmer at times.

Discussion

The present study examined the extent to which manipulations of glare intensity and clothing configuration affected participants' estimates of the distance at which they would first recognize a roadside pedestrian walking next to a vehicle that was stopped on the left shoulder. Both glare intensity and clothing condition were manipulated within-subjects so that participants were exposed to all six conditions. Three Glare intensities

were tested: none (parking lights only), mild (low beams + fog lights, filtered), and stronger (low beams + fog lights). Participants were asked to imagine the presence of a pedestrian in one of two Clothing conditions (Street clothing or Vest) with the aid of photographs of a pedestrian and to respond by pressing a button when they reached the point at which they judged that they would first recognize a pedestrian were present adjacent to the glare vehicle.

The interaction between Glare intensity and Clothing condition indicates that the effect of Glare intensity was dependent upon Clothing condition. Estimated recognition distances for the Street clothing condition decreased as Glare intensity increased while estimates for the Vest condition remained relatively constant. As Glare intensity increased, the difference in estimated recognition distances between estimated recognition distances for the two Clothing conditions also increased. The difference between the Vest condition ($M = 134.7$ m) and the Street clothing condition ($M = 73.8$ m) was particularly large (1.8 times greater) in the Stronger glare condition, but the effect was only less than 60 m and less than 40 m in the Mild and Parking conditions, respectively.

This finding suggests that participants judged the effect of headlight glare differently, depending on the clothing configuration they were asked to imagine. Regardless of headlight intensity, participants judged that a pedestrian wearing a retroreflective vest would be more visible than a pedestrian wearing low contrast clothing (i.e., the Street clothing condition). Furthermore, participants judged that they would be less able to see the low contrast pedestrian as glare intensity increased, as estimates for

the Street clothing condition significantly decreased as glare intensity increased. Glare intensity had almost no effect on participants' judgments of their ability to see the pedestrian when wearing the retroreflective vest; participants judged that recognition distances for a retroreflective vest-clad pedestrian would not decrease in the presence of glare.

It is possible that the glare intensity manipulations used in the present study were not strong enough to yield greater differences. None of the participants reported noticing anything unusual about the headlights of the glare vehicle. Furthermore, just over 70% of participants rated the headlights as being either 'exactly the same' as or 'slightly different' from typical headlights. These findings suggest that either participants may not have noticed the differences in luminance produced by the glare manipulations or that they noticed the manipulations but judged them to be insufficient to affect their ability to see pedestrians.

As expected, when averaged across the glare conditions the Vest condition yielded significantly longer distances than the Street clothing condition. The mean estimated distance for the Vest condition was just over 50 m longer (160%) than that of the Street clothing condition, suggesting that participants recognized the improved conspicuity that retroreflective material offers pedestrians. This finding is neither new nor surprising. Extensive research (e.g., Rosenberg & Tyrrell, 2010; Tyrrell, Wood, & Carberry, 2004) has documented that participants typically believe that retroreflective vests enhance the conspicuity of pedestrians.

The findings of Experiment 1 offer insight into drivers' perceptions of the effects of glare on their visual abilities. Specifically, this study examined how well drivers judge that they can detect the presence of pedestrians at night given varying levels of glare from a nearby parked vehicle. The findings suggest that drivers' judgments of the effect of headlight glare on their ability to recognize a pedestrian are dependent upon the contrast of the pedestrian's clothing. In order to determine the extent to which participants' ability to recognize a pedestrian was *actually* affected by both glare intensity and clothing condition, participants in Experiment 2 were asked to indicate the point at which they first recognized a pedestrian given the same glare intensities and clothing conditions used in Experiment 1.

EXPERIMENT 2

Method

Participants

Ninety-one undergraduate Clemson University students (42 females, 23 males) 18-25 years of age ($M = 19.01$, $SD = 1.20$), participated in this study. Twenty-five participants' data were excluded as a result of the presence of headlights from extraneous vehicles during critical periods of testing or due to technical difficulties. Participants received course credit in exchange for their participation in the study. All participants were required to have normal or corrected-to-normal vision, achieved a visual acuity of at least 6/9.5 (20/32), and reported having no known visual pathology (other than refractive error). There was not a significant difference between the mean acuity of participants in Experiment 1 and Experiment 2, $t(84) = 1.01$, $p > .05$. Additionally, participants' contrast sensitivity was measured using the Pelli-Robson letter sensitivity chart; all participants achieved a minimum score of 1.55. Participants averaged 3.67 years of driving experience ($SD = 1.43$). Participants reported that, on average, 34.79% ($SD = 17.82$) of their driving took place at night.

Design

The present study included two independent variables: glare intensity and clothing. Both variables were manipulated between-subjects. A between-subjects manipulation of the independent variables is necessary for the measured recognition condition, as exposure to more than one condition could have introduced demand characteristics (Orne, 1962) and/or sensitize participants to the presence and location of the test pedestrian, as drivers are not typically aware of the location of pedestrians prior

to encountering them (Langham & Moberly, 2003). The manipulations of both the glare intensity and clothing variables were the same as those used in Experiment 1 (see Figures 1 and 5a and b). Participants were randomly assigned to one of the six glare/clothing combinations (see Table 1), with the exception of eight participants who were specifically assigned to one combination (Parking, Street) in order to increase the sample size for that condition. The dependent variable measured was the distance at which participants first recognized the pedestrian.

Table 1. Summary of experimental manipulations

Clothing Type	Levels of Glare		
	<i>None (Parking)</i>	<i>Low Beam + Fog lights filtered (Mild)</i>	<i>Low Beam + Fog lights (Stronger)</i>
<i>Street Clothing</i>	Street Clothing, No Glare	Street Clothing, Mild Glare	Street Clothing, Stronger Glare
<i>Retroreflective material</i>	Retroreflective, No Glare	Retroreflective, Mild Glare	Retroreflective, Stronger Glare

Procedure

The first portion of each experimental session was conducted in the same manner as in Experiment 1. Participants' informed consent was obtained, followed by an assessment of their binocular acuity and contrast sensitivity. An experimenter in the laboratory briefly explained the experimental procedure and participants were escorted to the test vehicle. The test vehicle utilized was the same as that in Experiment 1; all procedures involving the test vehicle were replicated as well. The glare vehicle and pedestrian were in the same location as the glare vehicle from Experiment 1 (see Figure 3). As in Experiment 1, participants were given a response keypad to press at the moment when they first recognized a pedestrian.

Participants were told that they were going to be driven on a short drive around campus (see Figure 10 for the route that was driven for all trials) and that they should look for pedestrians positioned on or near the roadway. The experimenter in the backseat instructed participants to “press the button each time that you see a pedestrian on the roadway or on the shoulder of the roadway ahead of you. Each time you see a pedestrian please press the button as soon as you become confident that you see a person (not just a thing).” Each participant experienced only one of the six combinations of clothing and glare intensity. Anytime a vehicle other than the glare vehicle was present on the roadway or shoulder of the roadway, the trial was cancelled if the extraneous vehicle was within sight during any of the time period during which the participant was within the sight distance (200 m) of the test pedestrian. This resulted in the exclusion of 20 trials from analysis; these trials were replaced with data from new participants. Either one or two participants completed the experiment at a time. During trials in which two were present, one sat in the front seat and one in the rear seat. The radio played music at a volume that prevented participants from hearing each other’s button presses. Three different male experimenters acted as the test pedestrian.

Once the test vehicle passed the test pedestrian, the participants were informed that the experiment had been completed and they were debriefed. They were returned to Brackett Hall where they read and initialed a debriefing form (see Appendix B) and completed a brief survey (see Appendix A).

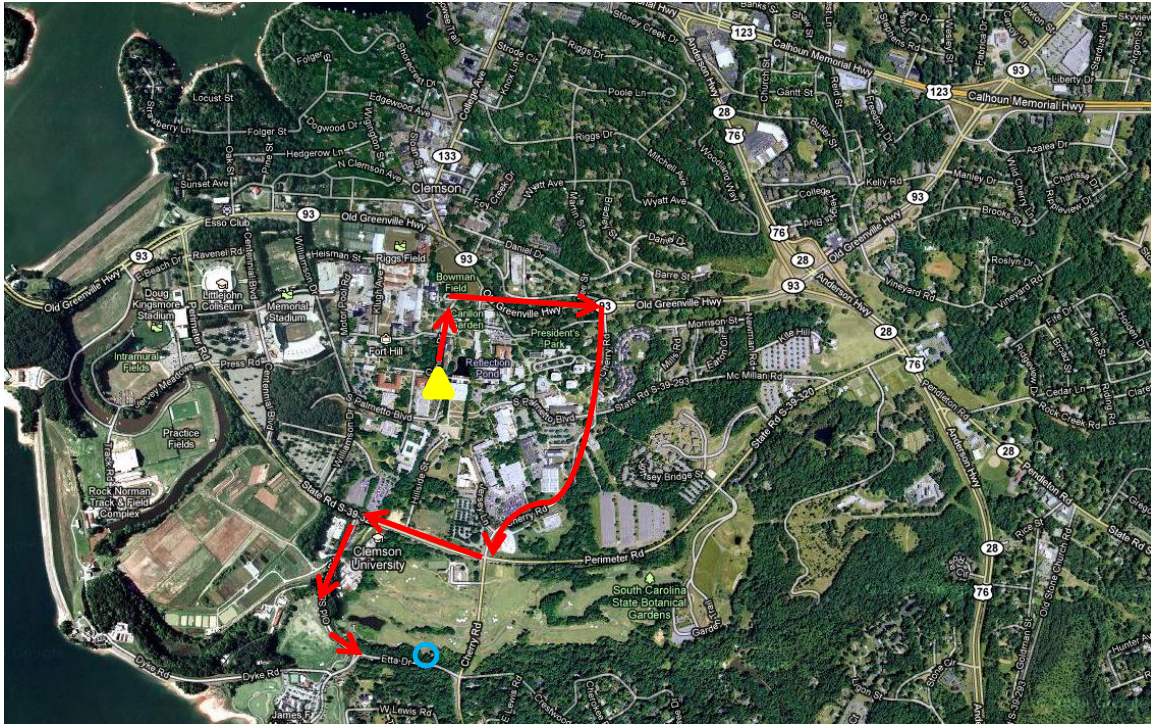


Figure 10. Route driven by the experimenter for measured recognition trials. The triangle represents the starting location and the circle represents the position of the glare vehicle and pedestrian. (The underlying map was taken from Google Maps, <http://maps.google.com>.)

Results

Prior to conducting analyses, the response distance data were examined for outlying values. One outlier ($z = 3.40$) was identified and removed from the data set. Thus, the data from 65 participants are reported here. Prior to analyzing these data, the homogeneity of variance assumption was satisfied. A $3 \times 3 \times 2 \times 2$ (Glare Intensity: Parking, Mild, and Stronger \times Pedestrian: one of three experimenters \times Clothing: Street and Vest \times Seat: front or back) between-subjects ANOVA was conducted in order to determine what effect, if any, Seat and Pedestrian had on recognition distances. Neither

Seat ($F(1, 37) = .18, p > .05$) nor Pedestrian ($F(2,37) = .41, p > .05$) had a significant effect on recognition distance; additionally, there were no significant interactions that involved Seat or Pedestrian. Thus the Seat and Pedestrian variables were removed from the model. A 3 x 2 (Glare Intensity: Parking, Mild, and Stronger x Clothing: Street and Vest) was conducted to examine the effects of Glare and Clothing on recognition distances.

There was a significant main effect of Glare intensity on recognition distances when averaged across Clothing conditions, $F(2,59) = 4.24, p < .05, \eta_p^2 = .13$ (see Figure 11). Bonferroni corrected pairwise comparisons revealed that recognition distances from the Parking condition ($M = 49.5\text{m}, SD = 31.1\text{m}$) were significantly greater (2.5x) than those in the Stronger glare condition ($M = 20.1\text{m}, SD = 33.5\text{m}$), $p < .05$. The differences between the Parking condition and the Mild glare condition ($M = 37.2\text{m}, SD = 38.0\text{m}$) and between the Mild and Stronger glare conditions were not significant, $p > .05$.

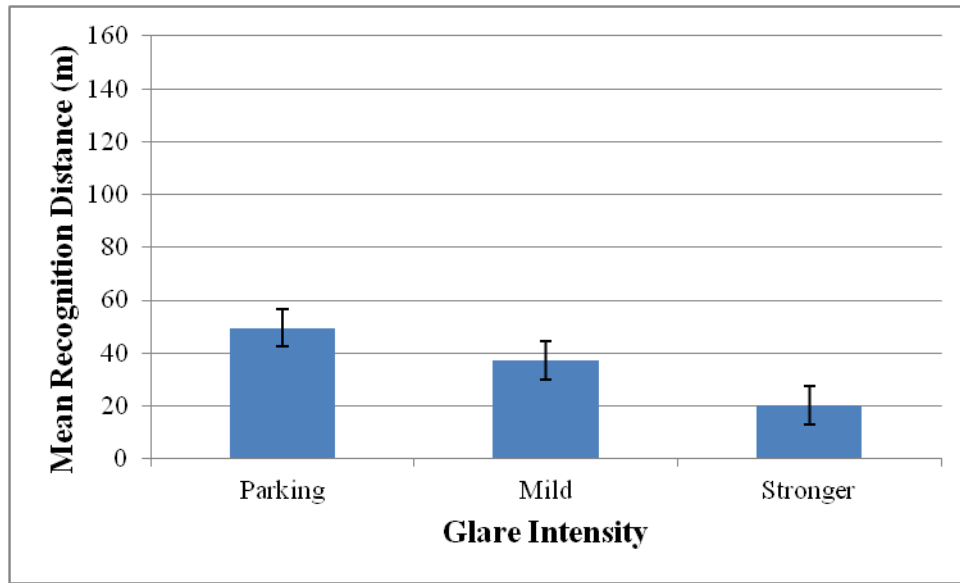


Figure 11. Mean (± 1 standard error of the mean) recognition distances (m) for each of the three Glare intensities. These values were averaged across the two Clothing conditions.

The ANOVA also revealed a significant main effect of Clothing, $F(1,59) = 4.75$, $p < .05$, $\eta_p^2 = .07$ (see Figure 12). When averaged across Glare conditions recognition distances for the Vest condition ($M = 44.7$ m, $SD = 43.6$ m) were significantly longer (1.7x) than those in the Street clothing condition ($M = 26.5$ m, $SD = 22.8$ m).

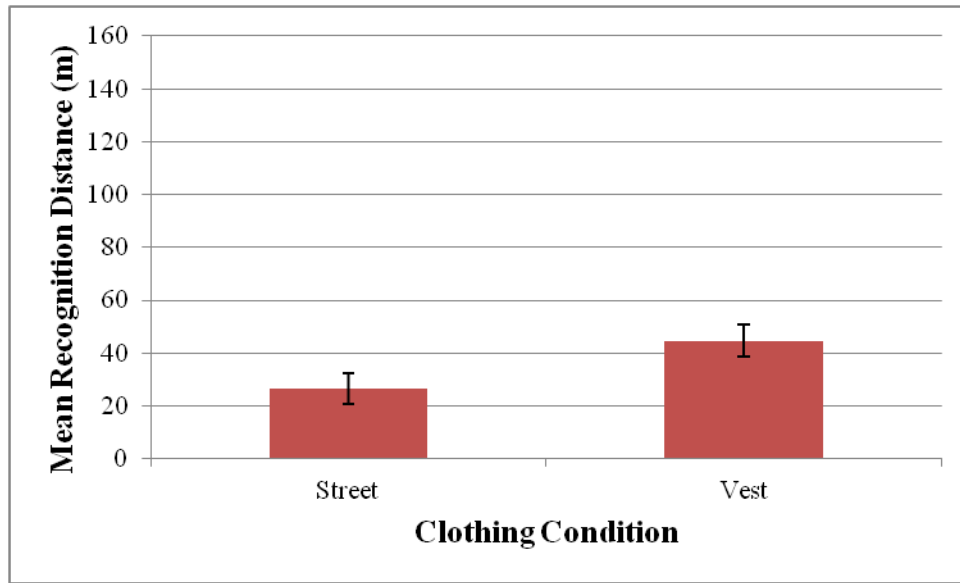


Figure 12. Mean (± 1 standard error of the mean) recognition distances (m) for the two Clothing conditions. These values were averaged across glare intensity conditions.

There was not a significant interaction between Glare and Clothing condition, $F(2,59) = .62, p > .05, \eta_p^2 = .02$. Thus, the relationship between Clothing condition and recognition distance was relatively consistent across Glare condition. The effects of Glare and Clothing conditions on recognition distances can be seen in Figure 13.

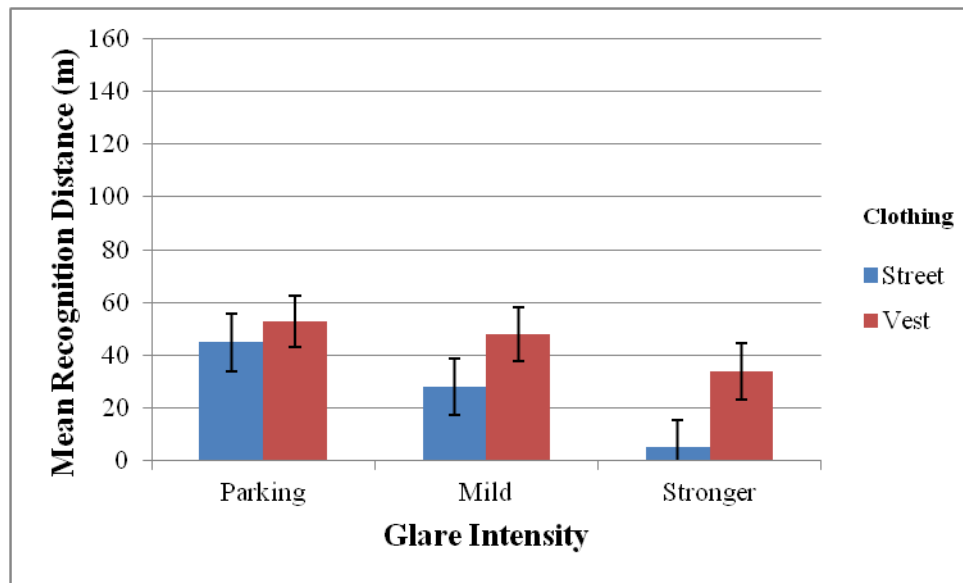


Figure 13. Mean (± 1 standard error of the mean) recognition distances (m) for the three Glare intensities and two Clothing conditions. The interaction between Glare intensity and Clothing condition was not significant.

Sixty-two of the 65 participants in the current study (95%) completed the post-experiment survey. Participants were asked if they noticed anything unusual about the stationary (glare) vehicle. Thirty-one (50% of survey respondents) participants indicated they had noticed something unusual about the glare vehicle. Participants were then asked to provide an explanation of their answer. One participant from the Mild glare condition (5.2%) mentioned that the lights appeared dimmer. Two participants in the Stronger glare condition (9.1%) reported that the headlights seemed bright. Many of the remaining responses commented on the presence of the pedestrian adjacent to the car.

Participants were also asked to rate the similarity of the glare vehicle's headlights to headlights typically encountered when driving at night on the same four-point scale used in Experiment 1, where a rating of one was 'exactly the same' and four was

‘significantly different.’ Overall, 30.65% of participants gave the glare vehicle a rating of two, indicating the glare vehicle was ‘slightly different’. Mean similarity ratings by glare condition can be found in Table 2.

Table 2. Mean similarity rating of the glare vehicle by glare condition.

	Glare Condition		
	<i>Parking</i>	<i>Mild</i>	<i>Stronger</i>
<i>Mean</i>	2.48	1.89	2.41
<i>SD</i>	1.12	.94	.91

On average, participants in the Parking condition rated the glare vehicle’s headlights as the most dissimilar from typical headlights ($M = 2.48$). Several participants in that condition further explained that the headlights appeared “really dim” or not activated. This finding is not unusual, as this condition was meant to serve as a control condition, projecting forward only a limited amount of illumination (see Figure 2).

Interestingly, participants found the headlights in the Stronger glare condition to be somewhat different from typical headlights ($M = 2.41$). Recall that the Stronger glare condition was a combination of low beam headlights and fog lights. Some participants remarked that the headlights appeared to be “brighter than usual headlights.” This may be in part due to the fact that the glare vehicle utilized xenon headlights, which drivers often report to be more discomforting than halogen headlights.

Fisher’s r to z' transformation was used to examine the difference in effect size of glare intensity on recognition distances across the two experiments. The effect size (η_p^2)

for Glare intensity from each experiment was first converted to an r value by taking its square root and then transformed using Fisher's function. The resulting z' values were used to calculate a z value. The resulting z was used in a z test in order to determine whether the effect of glare intensity was significantly different for estimated recognition distances (in Experiment 1; $\eta_p^2 = .11$) than for actual recognition distances (in Experiment 2; $\eta_p^2 = .13$). The results of the z test indicated that there was not a significant difference in effect sizes, $z = -.12$, $p > .05$. However, due to the different designs used in the two experiments (i.e., glare was manipulated within-subjects in Experiment 1 but between-subjects in Experiment 2), it was determined that the resulting effect sizes may have been inappropriate for such a comparison, due to the fact that the error sum of squares calculation is reduced for within-subjects designs because of the correlations among measures (Olejnik & Algina, 2003). Thus, within-subjects effect sizes may not be directly comparable to those effect sizes obtained with a between-subjects design.

In order to further explore the differential effect of headlight glare on estimated recognition distances (Experiment 1) and actual recognition distances (Experiment 2), a linear regression model was developed based on two factors: Glare intensity and Measurement type (estimated; Experiment 1 or actual; Experiment 2). Measurement type was dummy coded such that a 0 represented estimated distances and a 1 signified actual distances. Estimated recognition distances from Experiment 1 were averaged across Clothing condition, providing a mean estimated recognition distance for each Glare condition from each participant. An interaction term (Measurement x Glare) was also created by multiplying the Measurement value (either 0 or 1, depending on the

experiment data were taken from) and Glare condition for each type of recognition distance. The creation of the interaction term allowed a statistical examination of the extent to which the effect of glare was consistent between estimated and actual recognition distances. The Measurement and Glare variables were entered in the first step of the regression analysis and the interaction term was entered in the second step.

In the first model, both Glare and Measurement type (estimated recognition) were significant predictors of Recognition Distance, accounting for 51% of the variance in the model. Including the interaction term in the second model did not significantly increase the R^2 of the model (see Table 3), indicating that the effect of glare was not significantly different between estimated and actual recognition distances. The slopes of the regression lines for both estimated and actual distances were not significantly different. Thus, while actual recognition distances were significantly shorter than estimated recognition distances, the detrimental effect of headlight glare was relatively consistent between estimated and actual measurements of recognition distances, as seen in Figure 14.

Table 3. Reported statistics for the regression models.

Step	Variables Entered	B	SE	Beta	ΔR^2	ΔF
1	Glare	-38.97	13.83	-.18	.514	66.005*
	Measurement	-252.52	22.67	-.69		
2	Measurement x Glare	-24.10	27.69	-.15	.003	.758

Note: * denotes significant at the .05 level



Figure 14. A comparison of mean estimated recognition distances (obtained in Experiment 1) and actual recognition distances (obtained in Experiment 2) by Glare intensity. Error bars are not shown because the manipulations in Experiment 1 were within-subjects, while the manipulations in Experiment 2 were between-subjects.

A separate regression analysis was used to examine the differential effect of clothing on estimated and actual recognition distances. Distance was predicted by two factors: Measurement type (estimated or actual) and Clothing condition. Measurement type was again dummy coded such that a 0 represented estimated distances, while a 1 represented actual recognition distances. Estimated recognition distances were averaged across Glare intensity in order to calculate a mean distance for each Clothing condition for each participant. Measurement type was multiplied by Clothing, creating an interaction term that allowed for a statistical examination of the potentially differential effect of Clothing between estimated and actual recognition distances. The Measurement

and Clothing variables were entered as the first step of the regression analysis, while the interaction term was entered in the second step.

The results of the first model indicated that both Clothing and Measurement type (estimated recognition) were significant predictors of recognition distance. Together, the predictors accounted for 52% of the variance in the model. Adding the interaction term to the model significantly increased the R^2 of the model (see Table 4), indicating that the effect of Clothing condition depended on Measurement type (estimated vs. actual recognition). As seen in Figure 15, the difference between estimated and actual recognition distances in the Vest condition (96.6 m; 31.6%) was greater than the difference in the Street clothing condition (61.6 m; 30.1%).

Table 4. Reported statistics for the regression models.

Step	Variables Entered	B	SE	Beta	ΔR^2	ΔF
1	Clothing	31.87	13.83	7.72	.518	55.977*
	Measurement	-77.21	22.67	7.90		
2	Measurement x Clothing	-30.26	27.69	15.60	.017	3.765*

Note: * denotes significant at the .05 level

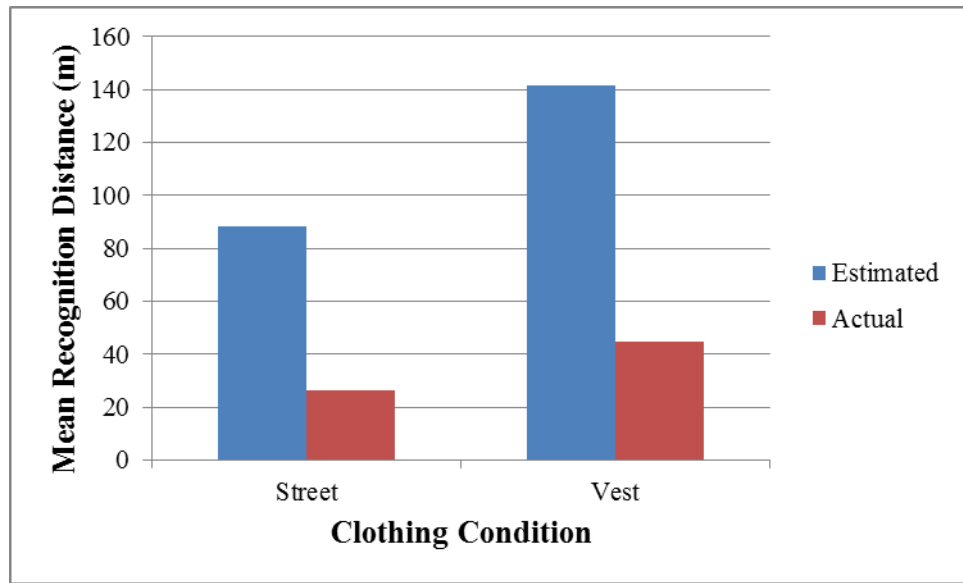


Figure 15. A comparison of mean estimated recognition distances (obtained in Experiment 1) and actual recognition distances (obtained in Experiment 2) by Clothing condition. Error bars are not shown because the manipulations in Experiment 1 were within-subjects, while the manipulations in Experiment 2 were between-subjects.

In order to determine if a three-way interaction between Glare Intensity, Clothing, and Measurement type exists, data from both experiments were organized such that recognition distances were coded to indicate whether it was an estimated or actual recognition distance (see Figure 16). Each data point was also coded for both Clothing and Glare. Two 3 x 2 x 2 ANOVAs were conducted: one model included the three-way interaction term and one did not. The resulting R^2 values (.50 for both tests) were used to calculate an F value to test the statistical significance of the difference in R^2 values. The non-significant results of this test ($F(2,179) < 1.00, p > .05$) indicated that the inclusion of the three-way interaction term did not significantly alter the R^2 of the model; thus, the interaction between Glare intensity, Clothing, and Measurement type was not significant.

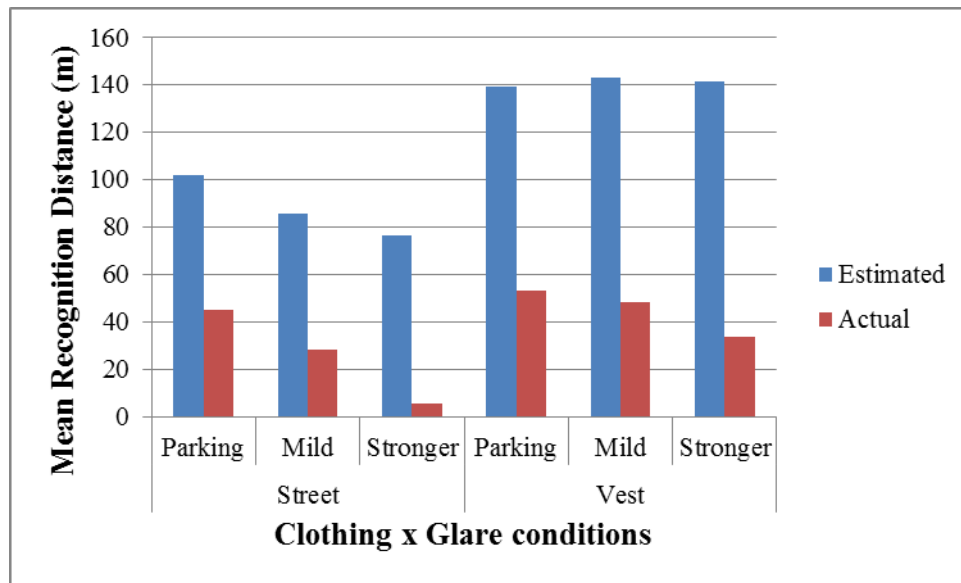


Figure 16. A comparison of mean estimated recognition distances (obtained in Experiment 1) and actual recognition distances (obtained in Experiment 2) as a function of Glare intensity and Clothing condition. Error bars are not shown because the manipulations in Experiment 1 were within-subjects, while the manipulations in Experiment 2 were between-subjects.

Discussion

Experiment 2 examined the effects of glare intensity and pedestrian clothing contrast on the distance at which participants recognized the presence of a pedestrian along the roadway. The glare intensities and clothing conditions in this study were intentionally matched to those used in Experiment 1. However, both Glare and Clothing were manipulated between-subjects in the current study. It was hypothesized that participants' recognition distances would not significantly decrease as glare increased. It

was hypothesized that the Vest condition would result in longer recognition distances than the lower contrast Street clothing condition.

Contrary to the hypotheses, there was an effect of Glare on participants' recognition distances. As glare intensity increased, recognition distances decreased such that the longest recognition distances were those associated with the lowest level of glare (Parking, $M = 49.5$ m) and the shortest distances were found in the highest glare intensity (Stronger condition, $M = 20.2$ m). This finding is in direct contrast to those of Balk and Tyrrell (2010), who reported that increases in glare intensity did not result in significant declines in visual abilities. This difference may be attributed in part to at least two factors. First, in Balk and Tyrrell's on-road experiment, a high contrast retroreflective stimulus was used to measure estimated and actual visibility distances. Due to the high contrast nature of the stimulus, it may have been fairly robust to the effect of glare. In the present study, the higher contrast clothing condition (Vest) may not have resulted in a high enough level of contrast; that is, the contrast of the retroreflective vest may not have been as robust to the effect of glare as the stimulus used in the Balk and Tyrrell study. This may be in part due to the location of the pedestrian in the current study, as he was positioned on the opposite shoulder of the roadway from the test vehicle carrying participants, thus limiting the amount of light reaching the pedestrian. Second, Balk and Tyrrell's participants knew exactly where the stimulus was located and when they should look at it (thus increasing the probability of foveal detection), while the participants in the present study were unaware of where or when a pedestrian might appear. Participants in the current study were not told where any pedestrians would be located, making the task

of recognizing the pedestrian more characteristic of typical nighttime driving. Because participants were unaware of the location of the pedestrian, the probability of foveal detection was considerably lower than in the Balk and Tyrrell study. It is likely that participants' initial detection of the pedestrian was peripheral, decreasing response distances.

While the results of the present study differ from those reported by Balk and Tyrrell, the findings are similar to other studies that have examined the effect of headlight glare on drivers' visual abilities. Theeuwes et al. (2002) found that the distance at which drivers detected a simulated pedestrian decreased as glare intensity increased. Detection distances were eight meters longer (77%) when headlight glare was absent. In the present study, the mean recognition distance in the Parking condition was almost 30 m longer (41%) than the mean distance in the Stronger glare condition, suggesting that headlight glare does affect drivers' ability to recognize a pedestrian at night.

Stafford, Whetsel, Balk, Ballou, and Tyrrell (2011) conducted a study similar to that of Balk and Tyrrell in that Stafford et al. measured participants' estimated and actual recognition distances in the presence of low and high beam glare from an oncoming vehicle. While Balk and Tyrrell presented participants with a high contrast retroreflective stimulus, Stafford et al. used a non retroreflective stimulus, thus decreasing the luminance and contrast of the stimulus. With this stimulus Stafford et al. found that actual recognition distances decreased by over 40% when the glare vehicle switched from low to high beam headlights. Similarly, recognition distances in the present study decreased by approximately 40% when comparing Parking to Stronger glare, indicating that as glare

intensity increases, the distance at which participants were able to recognize the pedestrian decreased.

As expected, Clothing condition significantly affected participants' recognition distances. Recognition distances in response to the pedestrian when wearing the retroreflective Vest were greater than those found in the Street condition. This finding confirms those of numerous studies (e.g., Balk et al., 2007, Wood et al., 2005) that demonstrated the enhanced conspicuity afforded to pedestrians by retroreflective materials. While the retroreflective vest did yield significantly longer recognition distances than the lower contrast clothing condition, the mean recognition distance in the Vest condition was still only 44 m (a 59% increase).

Wood et al. (2005) measured the distance at which drivers first recognized a pedestrian in four clothing configurations: black, white, vest, and biological motion. When drivers used low beam headlights in the absence of headlight glare, drivers recognized a pedestrian wearing the vest at a mean distance of 43 m. This distance closely matches the mean recognition distance for the Vest condition in the present study when averaged across glare intensities. However, when glare was minimal in the current study (Parking), the mean recognition distance of the pedestrian in the vest was 53 m. When the highest glare intensity (Stronger) was presented, the mean recognition distance decreased to 34 m. This finding suggests that the effectiveness of the vest in enhancing pedestrian conspicuity is decreased when drivers are faced with headlight glare from an oncoming vehicle.

The results of the present study contribute to existing research on both pedestrian conspicuity and the effect of headlight glare on drivers' visual abilities. Previous research (e.g., Stafford et al., 2011 and Theeuwes et al., 2002) has reported the detrimental effect of headlight glare on drivers' visual abilities. The results of the present study confirm these findings. The effect of clothing condition on recognition distances also confirms previous findings that the addition of retroreflective material to a pedestrian's clothing can enhance the pedestrian's conspicuity. Future research should examine the interactive effects of headlight glare and other clothing configurations (e.g., biomotion) on drivers' ability to recognize pedestrians in realistic driving situations.

GENERAL DISCUSSION

Two experiments examined the accuracy of drivers' judgments of the effect of headlight glare on their ability to recognize a pedestrian. In the first experiment, participants estimated the distance at which they would first recognize a pedestrian in the presence of three different glare intensities. In Experiment 2, the distance at which participants actually recognized a pedestrian walking in place on the left shoulder was measured. Because the glare intensities were matched across the two experiments a direct comparison of the results of the experiments allows for an examination of the accuracy of participants' judgments of the conspicuity of the test pedestrian.

Comparing of the findings from Experiments 1 and 2 reveals that participants failed to appreciate how difficult it is for drivers to see roadside pedestrians, since estimated recognition distances were consistently and dramatically longer than the actual distances at which the roadside pedestrian was recognized. Figure 17 illustrates the difference between estimated and actual recognition distances when both estimated and actual recognition distances are averaged across Glare intensity and Clothing; the mean distance at which participants in Experiment 1 estimated that they would be able to see the pedestrian was over three times greater than the mean distance at which the participants in Experiment 2 responded.

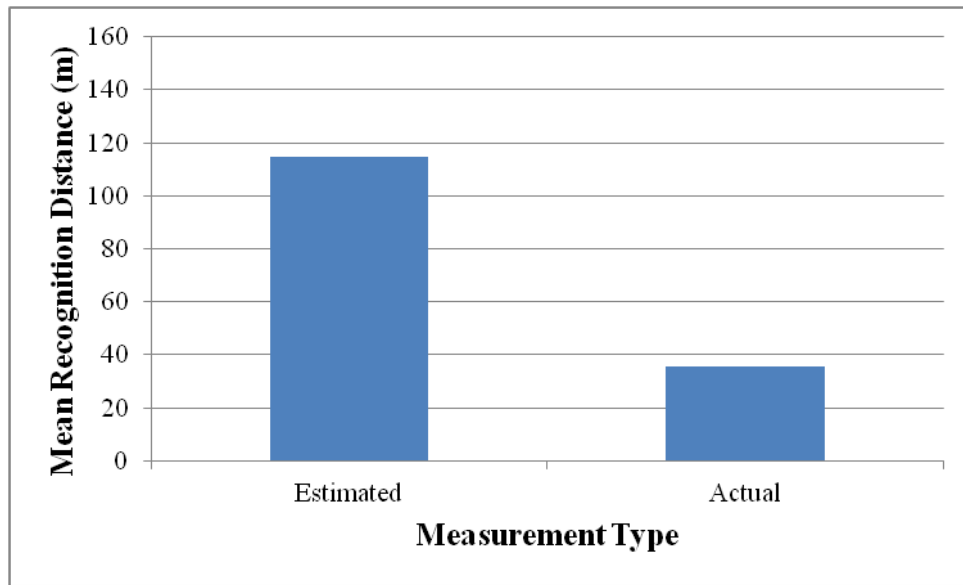


Figure 17. Mean recognition distances (m) by measurement type: Estimated (Experiment 1) and Actual (Experiment 2). Error bars are not shown because the manipulations in Experiment 1 were within-subjects, while the manipulations in Experiment 2 were between-subjects.

The disparity between estimated and actual recognition distances is similar to findings of numerous studies that documented pedestrians' estimates of their own visibility. Ferguson (1944) was the first to ask pedestrians to estimate their own visibility and found that 84% of estimates were longer than actual visibility distances. A follow up study conducted by Allen et al. (1970) extended Ferguson's finding, reporting that over 95% of participants overestimated their visibility and estimates were up to three times greater than actual visibility distances. More recently, Tyrrell, Wood, and Carberry (2004) reported that pedestrians overestimated their own visibility by a factor of 1.8x relative to actual visibility distances. Prior to the present studies no research has examined estimates of pedestrian visibility in the presence of glare. An examination of

the effect of glare on pedestrian visibility is particularly important given the large number of complaints the NHTSA receives from drivers regarding headlight glare. Findings from the current studies suggest that headlight glare may impact observers' overestimates of pedestrian visibility. The difference between estimated and actual recognition distances was particularly large when Stronger glare was presented to participants, as estimates were over 5x greater than actual recognition distances (compared to only 2.4x greater in the Parking condition). It may be the case that observers do not fully understand the effects that headlight glare has on the distance at which a pedestrian can be recognized, given that estimates from Experiment 1 did not significantly vary as function of headlight glare.

Two recent studies have examined the relationship between observers' estimated and actual visibility distances when headlight glare from an opposing vehicle is present. Stafford, Whetsel, Balk, Ballou, and Tyrrell (2011) conducted a study similar to that of Balk and Tyrrell in which observers' estimated and actual visual abilities were measured; however, a non-retroreflective stimulus was used (as opposed to the retroreflective stimulus used by Balk and Tyrrell). Stafford et al. found that observers' estimates of the effect of glare on visual abilities were fairly accurate (i.e., estimated and actual recognition distances were not significantly different), with a non-significant tendency to overestimate the distance at which they would recognize the stimulus. Thus, the findings presented by Stafford et al. are somewhat contradictory to those reported by Balk and Tyrrell. Participants overestimated the effects of glare when a retroreflective stimulus was used (Balk & Tyrrell), but this was not the case when using a non-retroreflective

stimulus (Stafford et al.) The present studies were motivated by a desire to reconcile the results of these two studies in an effort to achieve a deeper understanding of drivers' judgments of the effects of headlight glare when the stimulus presented was a pedestrian. In addition, by using pedestrians as the stimulus (as opposed to an optotype), the present studies added an important degree of face validity.

When the results of the two experiments are averaged across clothing (see Figure 14), there was a non-significant trend in the data suggesting that participants underestimated the effect the debilitating effects of headlight glare. Estimates were 2.4x greater than actual recognition distances in the Parking condition, 3x greater in the Mild, and over 5x greater in the Stronger condition. This finding suggests that participants may have underestimated the debilitating effects that headlight glare can have on their ability to recognize a pedestrian, particularly when glare intensity was at its highest.

While estimated recognition distances appear to be longer than actual recognition distances in the present studies (see Figure 16), the magnitude of the effect of glare is relatively consistent (i.e., not significantly different) between the two. While there appears to be a slightly greater decrease in actual (rather than estimated) recognition distances as glare increased (see Figure 14), the results of the regression analysis comparing the effect of headlight glare on estimated and actual recognition distances suggest that the effect of glare is consistent across the two experiments. In addition, the effect sizes from the two experiments were not significantly different. Thus it appears that the participants in Experiment 1 judged the effect of glare to be of roughly the same

magnitude as it really was for the participants in Experiment 2. Consistent with the results of the regression, the effect size of glare was similar between the two experiments.

It may be the case that in both the present studies and that conducted by Stafford et al., participants were presented with stimuli of a familiar level of contrast. Stafford et al. used a non-retroreflective stimulus and found that participants more accurately estimated the effect of headlight glare. In the present study, both a retroreflective (Vest condition) and non-retroreflective (Street clothing condition) version of the stimulus (i.e., the pedestrian) were presented to participants. An examination of the differential effect of Clothing between estimated and actual recognition distances illustrated another key finding; the difference between estimated and actual recognition distances depended upon the clothing configuration. Participants' estimates of recognition distance were 61 m longer than actual recognition distances in the Street clothing condition, while the Vest condition yielded a difference of almost 97 m (see Figure 15). This finding suggests that drivers may have a more accurate understanding of the effect of headlight glare on their visual abilities when the stimulus presented to them is not retroreflective. The tendency for smaller overestimates of recognition distances in the Street condition is consistent with the findings presented by Stafford et al. in that participants in that study viewed a non retroreflective stimulus and were able to accurately estimate the effect of headlight glare on recognition distances. The findings of the present studies combined with those Stafford et al. suggest that drivers may have a more accurate understanding of the effect of headlight glare on recognition distances when the stimulus being recognized is not retroreflective. It may be the case that drivers are less familiar with the artificially high

contrast nature of a retroreflective stimulus, while they may be more familiar with a non-retroreflective stimulus. Thus, participants in the current studies were able to more accurately estimate recognition distances when the pedestrian did not wear a retroreflective clothing configuration.

There were a few limitations to the present studies. Neither low beam headlights alone (i.e., without active fog lights) nor high beam headlights were presented to participants as a source of glare. Future research should examine the effect of both low and high beam headlights on drivers' estimated and actual ability to recognize pedestrians at night. This may be more applicable to situations drivers typically encounter at night and offer a better understanding of perceived and actual effects of headlight glare.

The experimental test site was a roadway with very little ambient illumination and data were not collected when extraneous traffic was present. The site was specifically chosen to isolate the effect of glare intensity on participants' estimated and actual recognition distances. However, ambient illumination (e.g., streetlights) and the presence of other (i.e., leading, following, and opposing) vehicles on the roadway can affect a driver's ability to recognize a pedestrian. Additionally, the roadway used for the present experiments was subject to low vehicle and pedestrian traffic density, thus making this scenario a potentially unrealistic one. Drivers may typically encounter pedestrians in more urban and well lit areas than the one used in these studies. It may be the case that the availability of ambient illumination modifies the extent to which opposing headlights affect drivers' ability to see.

The participants who provided estimates of recognition distance in Experiment 1 were different from those whose actual ability to recognize the pedestrian were measured in Experiment 2 in order to minimize the influence of demand characteristics and to prevent participants from knowing where the test pedestrian was stationed when measuring actual recognition distances. Future research should aim to design an experiment in which the same group of participants are asked to provide both estimated and actual recognition distances of a pedestrian in the presence of headlight glare. Results from a study of this nature would be useful in supplementing the results of the current studies.

It is important to research not only the objective effects of headlight glare but also the subjective effects, as drivers' actions are likely to be affected by their beliefs about the extent to which their ability to see is altered by visual challenges such as headlights from oncoming vehicles. The results of the current studies provide a deeper understanding of drivers' beliefs about how their ability to recognize a pedestrian is affected by both glare from opposing headlights and the contrast of the pedestrian's clothing. It appears that drivers partially understand the effects of glare, particularly when a pedestrian is wearing a non-retroreflective clothing configuration. Future research should continue to examine this relationship in the context of pedestrian recognition, potentially using standard low and high beam headlights for both the glare and test vehicles and asking participants to provide both estimated and actual recognition distances during an experimental session.

APPENDICES

Appendix A

Post-test Questionnaire

Please answer each question as accurately as possible. If any question is unclear, please ask for clarification. All answers will remain confidential. Unless noted, assume all questions refer to average driving situations.

1. Age: _____

2. Gender: Male Female

3. Years of driving experience _____

4. Approximately what percent of your driving is done at night? _____

5. What percentage of the time do you use the specified headlight when driving at night in the following situations?

Use *low beams* when driving on *city streets* _____%

Use *low beams* when driving on *highways* _____%

Use *high beams* when driving on *city streets* _____%

Use *high beams* when driving on *highways* _____%

6. When you are driving on freeways at night, how frequently do the headlights of oncoming traffic seem troublesome?

Rarely _____

Occasionally _____

Often _____

At every encounter _____

7. Estimate the distance at which you can see the following objects when driving at night:
(in metres or feet)

Other vehicles: _____

Cyclists: _____

Pedestrians wearing white: _____

Pedestrians wearing black: _____

Traffic signs: _____

The following questions are in regards to tonight's experiment.

1. Did you notice anything unusual about the stationary vehicle that was used in tonight's experiment?

Yes No

2. If yes, please explain.

3. What type of headlight beams did the stationary vehicle use tonight? (please check one)

☐ Low beams
☐ High beams
☐ Sometimes low beam, sometimes high beam
☐ Neither low beams nor high beams

4. On a scale from (1) *exactly the same* to (4) *significantly different*, how similar was the stationary vehicle's headlights compared to typical headlights?

Exactly the same	slightly different	somewhat different	significantly different
(1)-----	(2)-----	(3)-----	(4)

5. Please explain your answer.

Appendix B

Debriefing Form

Additional Pertinent Information Permission to Use Data Collected in a Research Study Clemson University

Perceived and Actual Effects of Glare on Pedestrian Recognition at Night
Thank you for participating in this study. Now that you have completed your participation, we want to let you know that this study involves two groups of participants and that you were randomly assigned to one of these two groups. As you know, your group (the “lookers”) is being asked to look for pedestrians during the short drive. The other group of participants (the “estimators”) have a somewhat different experience. The participants in the other group were told where our stationary vehicle would be located and they were asked to imagine that a pedestrian were positioned next to that vehicle. The headlights and fog lights of that vehicle were turned off. During their drive the other participants were asked to estimate the distance at which they would be able to respond to that (imagined) pedestrian if the vehicle’s headlights and fog lights were turned on. Once we have all of our data we will compare the other group’s estimates of their ability to see a pedestrian with your group’s actual ability to see the pedestrian. We did not disclose to you the existence of the other group of participants because we did not want you to know in advance where to look for the pedestrian.

Because we did not inform you about the other group of participants at the beginning of this study, you now have the option to either have us destroy the data we just collected or you can give permission for us to keep your data and use it for research purposes. Please initial below to indicate your choice.

_____ You may not use the data collected from me. Please destroy all data collected from me immediately.

_____ I give permission to have my data used in this research project.

Please remember that some of your classmates also may be signed up for this study. If they knew where our pedestrian was located that could negatively affect the results of this study, thereby wasting your time and ours. Therefore, we would appreciate it if you would not share this information with others who may be participating in this study.

Thank you again for your participation in this study!

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